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## WORLD POWER CONFERENCE

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THE SWEDISH SHALE AS RAW MATERIAL FOR PRODUCTION  
OF POWER, OIL AND GAS

by

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## INTRODUCTION

The Swedish Shale Oil Company, with their plant located in Närkes Kvarntorp, Sweden, is the only company mining the Swedish oil shale for production of power, oil and gas.

The plant has been described in more detail in previous reports [1,2]. This paper is concerned more or less to give a comparison of the results attained with the different pyrolysis methods, in connection with a short presentation of the processes.

The company was founded during the second world war and production started in April 1942. When the project was planned, no one had any idea which pyrolysis method would be the most suitable for Swedish oil shale. Therefore, from the very start of plant design three different retort methods were included for pyrolysis of oil shale. Later on, a method was added for pyrolysis of the oil shale »in situ«. Since the start the plant has been continuously at work for more than 14 years. During this time better methods have been developed and practical experience acquired. A technical and economical comparison between the different methods, on the present engineering standpoint, may therefore be justified.

## RAW MATERIAL

The richest Swedish oil shale is situated in the Province of Närke and originates from late-cambrian period. These deposits are divided into two areas and constitute a total quantity of 1,700 million metric tons. The

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rp plant is located at the shale deposit in the eastern part of the of Närke. Analysis of shale and ash, respectively, is shown in 1.

Table № 1.

S h a l e		A s h	
	18.0%	Si <sub>2</sub> O	60.7%
	2.0%	Fe <sub>2</sub> O <sub>3</sub>	11.2%
	6.3%	Al <sub>2</sub> O <sub>3</sub>	22.5%
moisture	1.9%	K <sub>2</sub> O	5.1%
ash	71.8%	Na <sub>2</sub> O	0.5%

e average calorimetric heating value varies between 2,000 and 2,200 r kg. (3,600—4,000 B.Th.U. per 1b.)  
e yield of oil accordance to the »Fischer assay« amounts to an average id 5.7%. The raw gas, formed in addition to oil during the pyrolysis, ating value depending upon the method of pyrolysis, but of the same magnitude as the extracted oil. After the pyrolysis a coke remains ng around 50% of the heat content of the shale. The low fusing tem- e of the ashes — around 950°C — makes combustion or gas generation esidual coke difficult.

## HANDLING OF SHALE

is a pre-requisite for the industry, because the Swedish shale is a w material, that mining, crushing, screening and transport do not o large expenditures. The deposits in the eastern part of the province e are favourable. The shale seam is practically horizontal and has um thickness of 16 meters (50 ft.) It is 2 to 4 kilometers wide and eters long in the east-west direction. In the deposit are layers of balls nious limestone to an amount of around 15%. The south portion of osit is covered by ordovician limestone, which in similarity to the the northern part, is thinned down by erosion during a later epoch. one third of the deposit — the part that presently is mined — has no e of limestone and instead has only an overburden of loose soil with age thickness of 7 m. (23 ft).

efly the handling of shale is as follows. The overburden is directly y a dragline, with a bucket of 8 m<sup>3</sup> (11 cubic yards) and 60 m. (175 ft) radius, into previously mined areas. Blasting is done in 100 mm vertically drilled holes, so that the shale remains »in situ«. The shale d by powered shovels, capacity 4 m<sup>3</sup> (5 cubic yard), and transported 20 ton trucks and then in similar size standard gauge railway cars. crushing is done by »Blakes« type jaw crushers and the intermediate e by medium size »Simon« gyratory crushers and screening by con-

ventional mechanically vibrated screens. After the coarse crushing the bituminous limestone is picked out by hand. Average efficiencies for the last few years computed on the basis of finished retort shale without bituminous limestone are shown in table № 2.

Table № 2

Required labour for shale handling	man hrs 1000 ton	164
Specific maintenance expenditures	Swedish kronor 1000 ton	1070
Consumption of explosives	kilograms 1000 ton	112

The annual consumption of shale in the pyrolysis retort units the last years has been around 1,800,000 ton, which corresponds to 2,350,000 ton pure shale from the mine. Simultaneously »in situ« consumption has been around 900,000 ton of the deposit.

## PYROLYSIS METHODS

1. The I.M. or Tunnel Kiln Retort, in which oil shale, screening size 30 to 80 mm, charged cars pass through a heating and pyrolysis zone in a tunnel. The gas enclosed in the tunnel circulates partly through the shale loaded cars and partly over pipe coils, in which as heating medium flue gas is circulating. This flue gas is generated in a separate gas — or oil fired furnace. The pyrolysis gas formed is drawn off, likewise the other methods, and oil vapour is condensed in a condensing unit adjacent to the kiln. Residual shale coke is discharged from the cars and burned in a separate unit. The IM-Kiln's part in the plant's total net production of crude oil, raw gas and steam, is around 11%.

### Advantages:

- The gas has a high heat value and a low percentage of oxygen. The design does not to any extent permit leakage of air or flue gas.
- The kiln can be fired by either gas or oil in desired proportions. The plant's total gas production can thereby be utilized without burning excess gas in the boilers or in flares.

### Disadvantages:

- The kiln requires a large amount of fuel in proportion to its production. The kiln's own gas production, after hydrogen sulphide, light gasoline and liquefied petroleum gas (propane and butane) have been extracted, covers only about 30% of the required amount of heat.

High maintenance and cleaning expenses. Construction difficulties due to temperature stress in the comparatively complicated tunnel. Further it is difficult to keep the cars running at high temperature. Running of heavy hydrocarbons in the circulating gas, cause deposits of coke in the tubes and cars. This requires periodic shut-down for de-coking and cleaning.

The residual coke is of pyrofore nature and has to be burned and pyrolyzed to avoid destruction of nearby vegetation. This requires a separate burning furnace[3], in which however superheated high pressure steam is generated.

**HG-Retort** is an improved Pumphreaston furnace with 72 retorts modified for Swedish shale. Each retort is 9 m (30 ft) long and 600—700 millimeter (24—28 inches) in diameter. Shale, screening size 30 to 80 mm, is charged into a hopper above the retort and the residual coke is continuously discharged through the lower end of the retort. Flue gas, generated in the retort, is used as a heating medium, and the gas — or oil burners for each retort, is the heating medium, and the gas around the retort. The HG-Retort's part in the plant's total net production of crude oil, raw gas and steam, is around 10%.

**Advantages:**

Yield of crude oil and raw gas is very high.

. The retort can be fired by either gas or oil in desired proportions. The plant's total gas production can thereby be utilized without burning gas in the boilers or flares.

**isadvantages:**

A certain inescapable dilution of pyrolysis gas with flue gas can not be avoided, due to flue gas leakage through the retorts.

In proportion to the retorts'own production the retorts require a large amount of fuel. Each retort's gas production, after hydrogenate, light gasoline and liquefied petroleum gas (propane and butane) been extracted, covers only around 75% of the required amount of heat. The residual coke is of pyrofore nature and has to be burned and used to avoid destruction of nearby vegetation. This requires a separate burning furnace[3], in which however high pressure superheated is generated.

The Kvarntorp-Retort is a modification of the Bergh Retort, fig. 1, designed especially for the Swedish oil shale. The shale, screened size 0 mm, is charged into an open hopper, from which the shale passes into a large number of small retorts, 2.2 m (7 ft 3 inches) long and 200—250 mm (8—9 inches) in diameter. The shale is discharged into combustion chambers from the lower end of the retorts. The combustion gases pass through the necessary amount of heat for the pyrolysis, and therefore no external source of fuel is required. On account of the low fusing temperature of the shale, separate La Mont heat absorption coils[3] are installed in the retorts.

the combustion chambers, and in these coils high pressure steam is generated. The Kvarntorp retort's part in the plant's total net production of crude oil, raw gas and steam, is around 60%.

**Fig. 1 — Section through shaft in the Kvarntorp furnace**

- 1 — Gas header, 2 — Charging hopper, 3 — Insulation, 4 — Fine gas outlet, 5 — Brick walls, 6 — High-pressure steam generating coils, 7 — Retort, 8 — Gas suction tube, 9 — Low-pressure steam distributor, 10 — Heat-absorbing surfaces in fuel bed, 11 — Discharging rollers, 12 — Discharging guide plates, 13 — Vibrator

**Fig. 1 — Section de la couche de combustible d'un fourneau  
Kvarntorp**

- 1 — Collecteur de gaz, 2 — Trémie de chargement, 3 — Isolant thermique, 4 — Sortie des fumées, 5 — Murs de briques, 6 — Serpentin générateurs de vapeur à haute pression, 7 — Cornue, 8 — Tube d'aspiration du gaz, 9 — Distributeur de vapeur basse pression, 10 — Surfaces absorbantes de chaleur dans la couche de combustible, 11 — Rouleaux de déchargement, 12 — Plaques de guidage du déchargement, 13 — Vibreur

**Fig. 1 — Querschnitt durch einen Schacht des Kvarntorpsöfens**

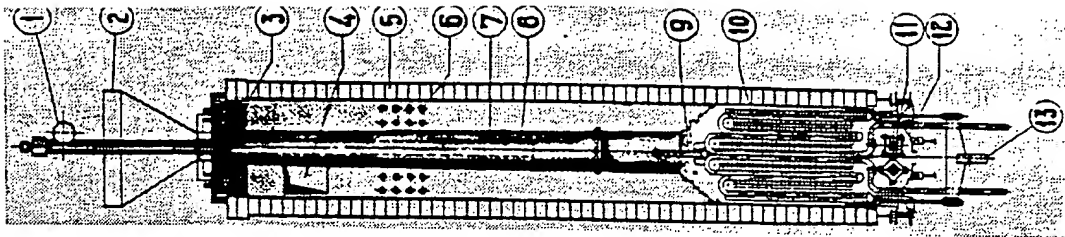
- 1 — Gassammelrohr, 2 — Schiefertrichter, 3 — Isolierung, 4 — Rauchgaskanal, 5 — Schachtwände aus Ziegeln, 6 — La Mont Kühlrohre, 7 — Retorte, 8 — Gasaussaugungsrohr, 9 — Niederdruckdampfverteiler, 10 — La Mont Kühlrohre im Koksverbrennungsschacht, 11 — Walze für Entfernung von Schieferasche, 12 — Bleche für Regelung der Entfernung der Schieferasche, 13 — Vibrator

Фиг. 1 — Разрез шахты печи „Кварнторп“

- 1 — Труба для отвода газа, 2 — Резервуар для добавки  
слапца, 3 — Изоляция, 4 — Выход дымового газа, 5 — Кир-  
пичные стены шахты, 6 — Охлаждающие трубы „Ла  
Монт“, 7 — Регорта, 8 — Выход для газа, 9 — Распреде-  
литель пара низкого давления, 10 — Охлаждающие трубы  
„Ла Монт“ в шахте для изжигания кокса, 11 — Цилиндры  
для вычерпания печи, 12 — Листы для вычерпания печи,  
13 — Вибратор.

**Advantages:**

- a. The furnace is producing adequate amount of heat for the pyrolysis.
- b. High pressure superheated steam is generated without intermediate steps.
- c. The yield of crude oil and raw gas is the highest in this type of retort, provided that the production from the other furnaces is corrected for the fuel concerned.



The retort is better suited for finer crushed shale than IM- and

orts. The furnace has proved to have extensive development possibilities. iginal Bergh-retort has been altered to such extent that production reased 150% in the same unit[3]. Available experimental test data e additional production increase of 50%. In consequence of this data orts are presently altered in accordance therewith, and no operating an therefore be rendered in this paper.

#### Advantages:

The raw gas has a low heating value. The reason is a large leakage and flue gas into the open ends of the retorts.

The furnaces are composed of many small parallel connected retorts, 1 3920, making it difficult to control the furnaces. In spite of this, the ours in proportion to production is the lowest in this type of the three in use.

Exceptional wear of heating coils.

The Ljungström method[4] involves electrothermal heating for pyro- in situ. Through hexagonally spaced electric underground heaters the is heated to pyrolysis temperature, and the gas is collected through ly spaced underground pipes. This method's part in the plant's total uction of crude oil, raw gas and steam, is around 19%. Therewith ion has not been done for used electric energy.

#### Advantages:

Obviously shale mining, crushing and any other handling of shale hes is not required.

Investment in plant is small.

Products are lighter than by the use of the retort methods giving aratively larger yield of gasoline and liquefied petroleum gas (propane itane).

#### Disadvantages:

Heating is done by electricity, with a large consumption of rather ive energy. The economy of the method is largely dependent on a supply of electric power, for which reason hydroelectric power is a te for this method.

The process is sluggish. It takes around half a year from the beginning ling period to full exploitation of the field.

The method has a definite premise as to form and position of the ed. A horizontal not too deep lying shale bed under a cover of non-s rock is necessary.

detailed production and technical comparison on the basis of equi-yield — and consumption figures are illustrated by the diagram fig. , — 4 and 5.

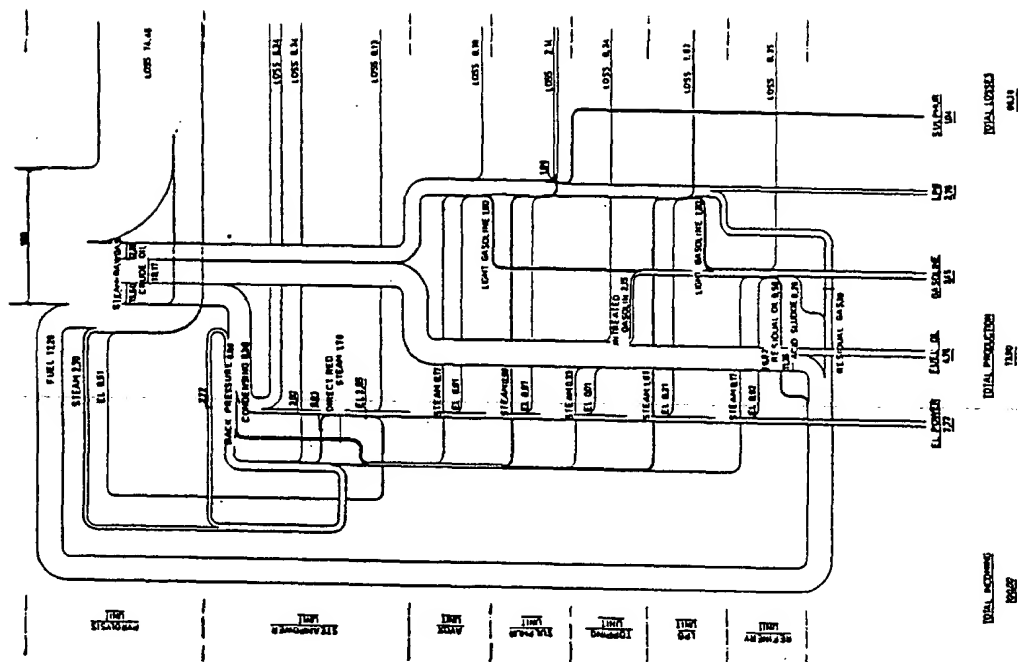
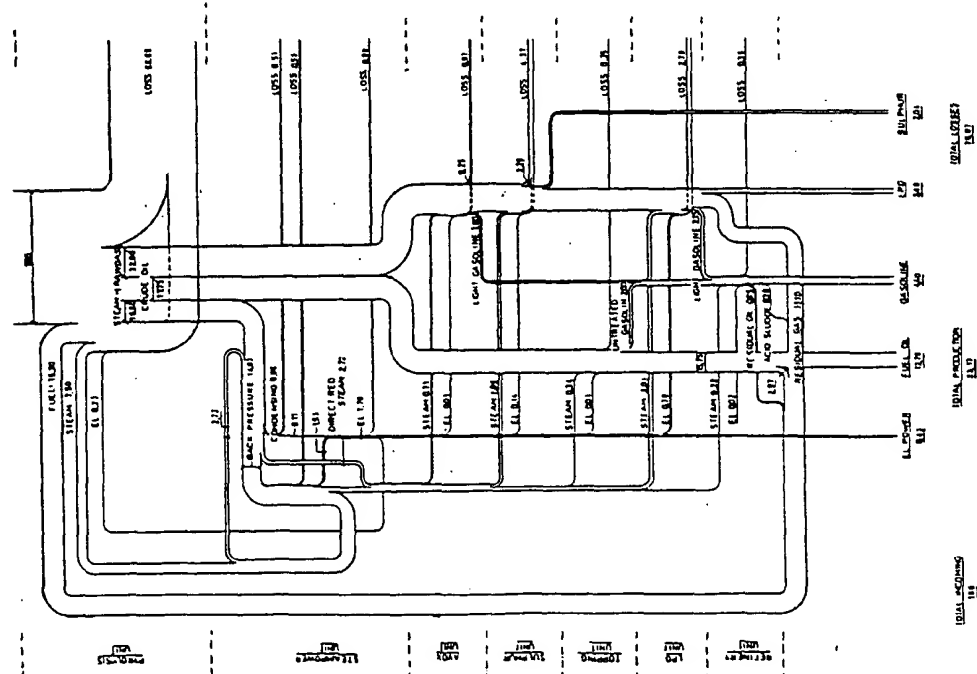


Fig. 2 — Sankey-diagram for oil-shale pyrolysis according to the IM Method and for the refining of crude products therefrom

Fig. 2 — Diagramme Sankey relatif à la pyrolyse du schiste par la méthode IM et au traitement consécutif des demi-produits qu'elle donne

Fig. 2 — Sankey-Diagramm für Schiefer-pyrolyse mit IM-Methode und für Weiterverarbeitung der dabei erzeugten Halbfabrikate

Фиг. 2 — Диаграмма „Санкей“ (Sankey) для пиролиза сланца по методу в туннельных печах и для дальнейшей обработки при том получении полу-фабрикатов

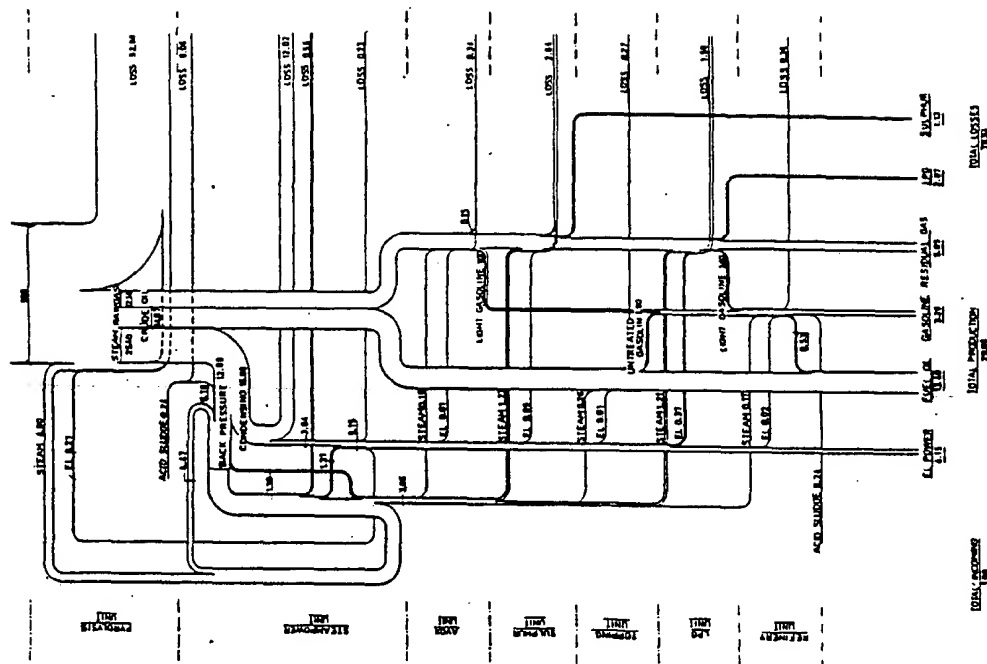


**Fig. 3 — Sankey-diagram for oil-shale pyrolysis according to the HG Method and for the refining of crude products therefrom**

Fig. 3 — Diagramme Sankey relatif à la pyrolyse du schiste par la méthode HG et au traitement consécutif des dérivés qu'elle donne

Fig. 3 --- Sankey-Diagramm für Schiefer-pyrolyse mit HG-Methode und für Welterverarbeitung der dabei erzeugten Halbfabrikate

Фиг. 3 — Диаграмма „Санки“ (Sankey) для пиролиза сланца по методу „Хг“ (HG) и для... (см. предыдущее)



**Fig. 4 — Sankey-diagram for oil-shale pyrolysis according to the Kvarn-torp Method and for the refining of crude products therefrom**

Fig. 4 — Diagramme Sankey relatif à la pyrolyse du schiste par la méthode Kvarntorp et au traitement consécutif des demi-produits qu'elle donne

**Fig. 4 — Sankey-Diagramm für Schiefer-pyrolyse mit Kvarntorp-Methode und für Welterverarbeitung der dabei erzeugten Halbfabrikate**

Фиг. 4 — Диаграмма... (см. предыдущее)... методу „Квартиторн“  
и для... (см. предыдущее)

By a comparison between the different pyrolysis methods certain specific values can be to a good guidance. Such comparative values for the last three years are shown in table № 3. As basic number for the various figures has been used produced million Mcal in form of crude oil, raw gas and steam. Regarding production of steam from residual shale coke, this is accomplished either direct or in a separate coke burning furnace[3]. In the latter case the required labour and maintenance costs are divided on the IM- and HG-Retorts, in proportion to delivered quantity of coke.

Table № 3

	Man hrs million Mcal	Pyrolysis methods			
		IM	HG	Kvarntorp	Ljungström
Required labour		780	630	220	290*)
Maintenance	Sw. Kronor million Mcal	4300	2900	1200	960*)
Availability	%	80	93	94	94

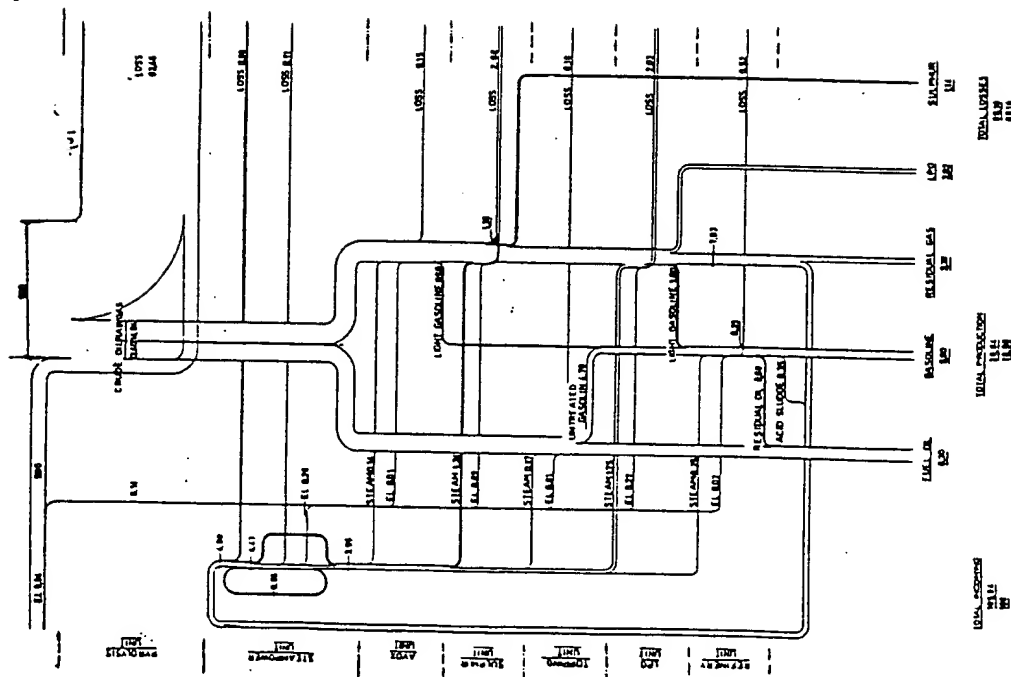
\*) In these cases consideration has not been taken to the consumption of electric energy, wherefore the produced Mcal is not net yield.

### FINISHED PRODUCTS UNITS

In the Kvarntorp plant refining of the crude products from the pyrolysis units is done in more or less conventional units. Only a brief description of the different units seems justified in connection with this paper.

1. The steam Power Unit is basing its activity upon the generated high pressure superheated steam (25 atm. pressure and 350°C) from the La Mont system inserted in the Kvarntorp retort furnace and the separate shale coke burning furnace. The generated steam goes through an 8 MW back pressure turbine. Normally 70 t/h, 25 atm. steam is going through this turbine producing around 6 MW and 5 t/h 11 atm., and 65 t/h, 3.5 atm. is delivered as process and utility steam for the plant. The surplus steam goes to condensing turbines of 8 respectively 12 MW. Around 150 million kWh has been generated yearly the last few years.

2. The Avox Unit[5] is based on a process of selective catalytic combustion of hydrogen with oxygen in the raw gas — normally 1.0 to 1.5% O<sub>2</sub>. The unit was fully processed, developed and designed by Kvarntorp employees. The oxygen is removed because it has a detrimental chemical effect and causes severe corrosion in subsequent units. Part of the light gasoline



5 — Sankey-diagram for oil-shale pyrolysis according to the Ljungström Method and for the refining of crude products therefrom

5 — Diagramme Sankey relatif à la pyrolyse du schiste par la méthode Ljungström et au traitement consécutif des demi-produits qu'elle donne

5 — Sankey-Diagramm für Schiefer-pyrolyse mit Ljungström-Methode und für Weiterverarbeitung der dabei erzeugten Halbfabrikate

5 — Диаграмма ... (п.) ... методу „Лунгстрём“ и для ... (см. пр.)

berbed before the raw gas enters this unit to avoid condensation in ng processes.

The Sulphur Recovery Unit is a conventional alcazide process for ion of H<sub>2</sub>S from raw gas. The H<sub>2</sub>S is converted into elementary r by the well known »Claus« process. The annual production in the r years has been around 30,000 ton.

The Liquefied Petroleum Gas (LPG) Unit is a conventional absorption i, in which light gasoline, propane and butane are absorbed under . pressure. Before this absorption process organic sulphur compounds verted to H<sub>2</sub>S by a catalytic process, after which the H<sub>2</sub>S is absorbed nventional etanolamine scrubber. The annual production the last few as been around 11,000 ton. LPG.

The Topping Unit is a common atmospheric distillation. The annual tion the last few years has been around 72,000 m<sup>3</sup> (450,000 bbl) fuel oil.

The Refinery Unit is an ordinary sulphuric acid process, modified to ie special character of the shale gasoline. The annual production the w years has been around 28,000 m<sup>3</sup> (175,000 bbl petrol)

#### SANKEY DIAGRAM FOR THE KVARNTORP PLANT

o bring about a comparison between the efficiency of the different is in Kvarntorp, complete Sankey diagrams, fig. no. 2, 3, 4, and 5, have eveloped for the whole plant based on previous production results. In ise each product, regarding raw material, production, consuming as s losses, has been expressed in heat equivalents. Presuming that the e heat content of the shale is 2,000 kcal/kg, this corresponds to 100 lents in the diagrams. The Sankey diagrams, one for each method, is a e of the production balance for a shale oil plant, based on each of the yrolysis methods.

ecause the finished products have different values in each country, a this connection no prolonged discussion take place regarding this rison. It should nevertheless be mentioned that the Kvarntorp retort , which has been the most developed, is superior to the other methods. iperiority of this system will probably be still more eminent in coun- where the electric energy is relatively expensive and mainly depending rmoelectrical energy sources.

#### THE SHALE OIL

s previously said, the oil products in Kvarntorp are fuel oil and gaso- aracteristics of the oils are shown in table № 4.

Table № 4

Standard-analysis of topped oil			
		Ljungström oil	Retort oil
Spec. gravity	dy <sup>20</sup>	0.934	0.997
ASTM-dist			
Fd	°C	187	185
5		203	219
10		211	234
20		224	259
30		298	281
40		255	308
50		265	331
60		280	351
70		291	373
80		315	378
90		341	
95		364	
End point		383	
Overdist.	%	98	
Rest	%	1	
Viscosity est			
	100°F	3.65	25.0
	210°F	1.34	3.33
Pour point	°C	< -60	-39
Ash	%	< 0.01	< 0.01
Carbon residue (Conradson)	%	0.35	4.6
Asphalt	%	0.03	0.79
S	%	1.19	2.05

What one especially notices regarding the oil from the Ljungström method is that the oil is essentially lighter than oil from the other methods. The shale oil has, independently of the pyrolysis methods, a high proportion of aromatics, as shown in table № 5.

Table № 5

Type analysis of the dieseloil fraction from retort oil	
	Rel. number C-atoms %
Aromates	35
Naphthenes	45
Paraffines	20
	100

The heavy oil from the retort method with a boiling point above 350°C is strongly aromatic and has a hydrogen content of only 8.4%. In this regard it is not suitable either for diesel oil or raw material for cracking or retreating oil. Thus no fractionation is done, and the topped oil is presently used as fuel oil. For further refining of the heavy oil is now proposed a coking and research work in this connection is now under way.

Regarding the gasoline can be mentioned that with conventional additives qualities are delivered: Research Octane № 88 and research Octane № 93.

## SHALE GAS

The raw gas, formed in the pyrolysis, has, depending on the pyrolysis conditions, rather various characteristics and composition as shown in tables 7 and 8.

Table № 6

over particular data showing the varities in the production chain of generated gas by each method

	After pyrolysis	After Avox	After Sulphur unit	After LPG unit
<i>quantity in cubic feet per ton shale</i>				
Pre-retort	45.0	42.3	32.6	30.4
Retort	98.0	95.0	75.6	72.6
Retort	30.0	29.4	21.0	18.0
Retort method	35.0		26.3	23.2
<i>heating value in Btu per cubic meter</i>				
Pre-retort	5,400	5,180	5,230	3,290
Retort	4,670	4,440	4,420	3,060
Retort	8,200	7,700	8,750	5,680
Retort method	8,550		9,100	6,850

values for raw gas given in the tables for each one of the pyrolysis have been computed under the theoretical assumption that each handled separately in the products units, although this of course is practically. Of particularly great interest is the gas after the LPG : the Kvarntorp plant it has been shown advantageous to add a unit reduction chain for ammonia, and this unit went on stream in November 1956. Necessary operating data to be presented in this paper are not at the present time. It can however be of interest to review the : for production of ammonia on the basis of shale gas a little more : On account of leakage of air and flue gas, especially with the Kvarntorp method the raw gas is diluted with nitrogen. It is evident that : nitrogen  $N_2$  to  $H_2$  if the hydrocarbon formed is steam cracked and the monoxide is converted to carbon dioxide and hydrogen, will be about the resulting mixed gas after the LPG unit, and is suitable for production of ammonia. For any other synthesis the nitrogen would be only : The nitrogen content is a little too low, but this can easily be corrected by addition of some air in the hottest zone of the cracking unit. The content is always too low in the raw gas from IM-, HG- and the : im methods, but in the raw gas from the Kvarntorp method the nitrogen is a little too high. Previously in this paper has been talked reconstruction of the Kvarntorp furnace unit, and in this reconstruction will be taken to lessen the leakage of air, so that even this gas, mixing, will be suitable for production of ammonia.

other circumstance which is speaking for production of ammonia step in the production chain, is that thanks to the Kvarntorp method, a surplus of steam, and in conjunction therewith, likewise power. However, under the presumption that the electric energy supply to the : im unit is arranged in some other way, for instance through buying electric power.

#### STEAM AND POWER PRODUCTION

account of the shales low hydrogen content, remains half of the : e in the form of coke after the pyrolysis. With the retort methods the : on of coke is accomplished, but in the case of the Ljungström : t is not utilized.

ashes, around 87% of the coke, has a fusion temperature of 950°C : fore an abnormal rise in temperature should be checked. This is : equally distributed cooling coils in the combustion chambers. The : is low, and around 6% of the coarse coke from the IM- and HG- : and around 4% of the finer coke from the Kvarntorp retort units, : rned. An other difficulty with the combustion of the shale coke is : sulphur content. The ratio S:C  $\approx$  4:11 is very high compared with : nal fuel. In consequence of this, the  $SO_2$  dewpoint is high, around : °C. The combustion gases can therefore not be cooled lower than to : e cooling coils are exposed to corrosion and abnormal wear, because

the design pressure does not correspond to a higher temperature than the dewpoint.

In an industry, where the chemical products is the essential thing, the steam pressure is selected more in consideration of operating safety than to power production. Unfortunately, when the Kvarntorp project was planned, nobody did anticipate any trouble or had any practical experience regarding this dewpoint, and therefore the plant has a very low power production in comparison to available fuel.

#### CONCLUSION

This paper is based on practical experiences and actual operating results have been presented. It has been shown that the Kvarntorp retort method, with no exception, is superior to any known method for pyrolysis of the Swedish oil shale. The Kvarntorp plant has at present passed the remunerative line, considering that production to certain extent is not done in rational units. In a recently published report(6), by a Swedish government committee, regarding future development of fuel and energy sources, attention is paid to the shale oil industry by a recommendation of extensive increase in plant facilities and production. This signifies, among other things, that successively operation will be converted only to the Kvarntorp retort method and complemented with eventual new methods primarily for pyrolysis of shale breeze, screened under 5 millimeter. The production program will be developed toward a higher refining:

1. The oil will be converted into motor fuel and coke.
2. The gas will be treated in accordance with previously stated methods but will also be used for hydrogenation of oils.
3. Power production will be increased by increasing the steam pressure to 79 atm. and the temperature to 450°C, in the operating units. By closing down the Ljungström unit and replacing it by additional Kvarntorp retort furnaces, the present annual power demand of 160 million kWh purchased from outside source, would be replaced by a net production of 200 million kWh.

This program signifies that Swedish oil shale will become a technically and economically competent raw material.

#### SUMMARY

The Swedish shale has a heat value of 2000 kcal/kg (3600 B.Th. U/lb), and an oil content of around 5.7% and produces by pyrolysis, besides the oil, also a gas with about the same heat content as the oil. The solid residue after the pyrolysis, the coke, has a heating value of 1000 to 1100 kcal/kg (1800 to 1980 B.Th. U/lb). The shale oil plant was constructed in the years 1941 and 1942 and was equipped with four different methods for pyrolysis, which have been improved during the years. Subsequently several unit for refining of

Intermediate products have been erected and so Kvarntorp has developed and more to a chemical industry on shale basis.

Results and experiences are given from the production and particular it is devoted to a comparison between the various methods for pyrolysis. Data are given and in addition a complete energy balance is shown of the whole production chain in the form of Sankey diagrams, one for the method developed in Kvarntorp, the data demonstrate that the improved method developed in Kvarntorp, the Kvarntorp furnace, gives the results.

The main products in Kvarntorp are oil, gas and steam. The oil is highly and at present is delivered as fuel oil and gasoline. The gas is used in the production of sulphur, propane, butane and ammonia. The steam from Kvarntorp furnaces covers the demand of process steam within the plant and excess is used for power generation.

## RÉSUMÉ

Le schiste suédois a une valeur calorifique de 2000 kcal/kg, une teneur en combustible d'environ 5,7% et donne, à la pyrolyse, en plus de l'huile, du même équivalent calorifique que l'huile environ. Le résidu solide de la pyrolyse — le coke — a une valeur calorifique de 1000 à 1100 kcal/kg. L'huile schisteuse de Kvarntorp a été construite en 1941—1942 et a été le résultat de 4 méthodes de pyrolyse différentes, qui se sont développées au cours des années. En outre, on a établi plusieurs sections pour la perfectionnement des produits demi-fabriqués, de sorte que, de plus en plus, Kvarntorp est devenu une entreprise industrielle chimique basée sur l'exploitation du schiste.

On dispose maintenant du résultat et des expériences acquis au cours de la production, et on s'est surtout intéressé à comparer les différentes méthodes de pyrolyse. D'une part on présente des renseignements de détail d'autre part une balance complète d'énergie pour toute la chaîne de production sous forme de diagrammes Sankey, un pour chacune des méthodes de pyrolyse. De toute évidence, la méthode Bergh — le fourneau «Kvarntorp» — qu'on a continué à développer à Kvarntorp, donne le meilleur

des produits principaux de Kvarntorp sont: huile combustible, gaz et L'huile est très aromatique et, jusqu'à nouvel ordre, elle est délivrée comme huile combustible et essence. On raffine le gaz en soufre, gasoil et L'huile. La vapeur des fourneaux Kvarntorp pourvoit aux besoins de qu'exigent les procédés de fabrication, et de l'excédent on tire de

## ZUSAMMENFASSUNG

Der schwedische Schiefer hat einen Wärmewert von 2.000 kcal/kg, einen t von ca. 5,7% und ergibt außer dem Öl ein Gas mit ungef. dem i Wärmehalt wie dem des Öles. Der feste Pyrolyserückstand — Koks — hat einen Wärmewert von 1.000 bis 1.100 kcal/kg. Das ölwerk Kvarntorp wurde in der Zeit von 1941—1942 gebaut und mit r verschiedenen Pyrolysemethoden ausgerüstet, welche im Laufe der r weiterentwickelt wurden. Ferner sind viele Abteilungen zur Verede- c Halbfabrikate hinzugekommen, so dass Kvarntorp immer mehr eine e Industrieanlage auf Schieferbasis geworden ist. Ueber die Resul- d Erfahrungen aus der Produktion wird in diesem Bericht Rechen- bgeleitet, wobei besonders der Vergleich der verschiedenen Pyrolyse- n Aufmerksamkeits gewidmet wird. Teils werden spezifische Daten n, teils wird eine kompl. Energiebalance für die gesamte Produktions-

ketten in Form der Sankey-Diagramme gezeigt und zwar für jede Pyrolyse-methode getrennt. Es hat sich herausgestellt, dass der «Kvarntorp»-Ofen, hervorgegangen aus dem «Bergh»-Ofen das beste Resultat gibt.

Die Hauptprodukte in Kvarntorp sind Öl, Gas und Dampf. Das Öl ist stark aromatisch und wird weitergeliefert als Brennstofföl und Benzin. Das Gas wird zu Schwefel, Gasöl und Ammoniak weiterverarbeitet. Der Dampf aus den «Kvarntorp»-Ofen deckt den Bedarf an Prozessdampf und aus dem Ueberschuss wird Energie erzeugt.

## РЕЗЮМЕ

Шведский сланец содержит — тепла 2.000 килокал./кг., масла 5,7% и дает при пиролизе кроме масла так-же газ, примерно того-же содержания тепла как масло. Твердый остаток после пиролиза — кокс — содержит от 1.000 до 1.100 килокал./кг. тепла. Предприятие обработки сланцев в Кварнторпе построено в 1941—42 г-ах и имеет четыре различных способа пиролиза, которые далее развиты в течении годов. Дальше пристроено много цехов для обработки полу-фабрикатов, так что Кварнторп все больше превращается в химическую промышленность на основе сланца.

Результаты и опыты настоящим опубликованы, причем особый интерес уделяется различным методам пиролиза. Выдаются специфические данные а так-же показывается полный баланс энергии целой цепи производства в форме диаграммы «Санки» (Sankey), одной диаграммы для каждого способа пиролиза. Оказывается, что далее обработанный метод Берга — т. н. «печ Кварнторп» — дает лучшие результаты.

Основные продукты в Кварнторпе — масло, газ и пар. Масло сильно ароматичное и вырабатывается в форме горючего масла и бензина. Газ обрабатывается в серу, т. н. «газол» и аммиак. Пар из печей Кварнторпа обеспечивает потребность пара для производства, а излишек пре-вращается в энергию.

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